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ORIGINAL PAPER

RFID-Enabled Traceability System for Consignment and High Value Products: A Case Study in the Healthcare Sector

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Abstract This paper presents a case study of a hospital operating room that evaluated a Radio-Frequency Identification (RFID)-enabled traceability system for the management of consignment and high value products requiring item level traceability. Results indicate that the traceability system in conjunction with the redesign of replenishment processes facilitates item level traceability, improves financial controls and case costing, upgrades service levels and reduces inventory shrinkage. Other benefits include time saved from non-value-added activities that can be transferred to patient care activities. The solution can be considered (i) as an alternative to RFID-enabled cabinets used in the replenishment of consignment and high value supplies in certain operating rooms, cardiac catheterization laboratories and interventional radiology departments, or (ii) as a complementary solution facilitating the tracking of medical devices removed from RFID-enabled cabinets. In short, the end-to-end traceability of medical products in the healthcare supply chain can be significantly enhanced.

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Keywords Supply chain management · Traceability · Radio frequency identification (RFID) · High value medical products · Hospital

Abbreviations

ABC	Activity-based costing
AHRMM	Association for healthcare resource & materials management
AIDC	Automatic identification and data capture
ANSI	American national standards institute
BPR	Business process reengineering
CHUM	Centre hospitalier de l'Université de Montréal
CMS	Clinical management software
EDI	Electronic data interchange
EMI	Electromagnetic interference
EPC	Electronic product code
ERP	Enterprise resource planning
HF	High frequency
HIBCC	Health industry business communications council
HIS	Hospital information system
IOS	Inter-organizational system
IT	Information technology
NPV	Net present value
OR	Operating room
RFID	Radio-frequency identification
ROI	Return on investment
RTLS	Real time locating system
RX	Prescription medication
SCM	Supply chain management
SGTIN	Serialized global trade identification number
SKU	Stock keeping unit
TID	Tag identifier
TPS	Toyota production system

Introduction

Hospitals and care facilities are extremely complex environments in which careful attention must be paid all the time. But doctors and nurses are only human, and unfortunately that means that errors are made. Sometimes the wrong dose is given to a patient. Or the wrong medicine. Or the wrong medical device is used. Or the right dose of the right medicine with the right device … but for the wrong patient […]. Establishing a traceability system is a key enabler to enhancing patient safety and improving the quality of care [1 p7].

Traceability is "the ability to track forward the movement of products through specified stages of the supply chain and trace backward the history, application or location of products under consideration" [2, p.12]. These products, or rather "traceable items", can take the form of any physical object without necessarily being a finished product ready for consumption. The product level at which the traceable items are defined, such as a component, unit, container or transportation unit depends on the industry and the required degree of control so that the correct traceable items can be tracked, traced, recalled or withdrawn [3]. In fact, organisations in various markets around the world have different objectives and ways of implementing traceability (e.g. for animal tracking [4], in the agricultural food chain [5], in the process industry [6], in the manufacturing industry [7], in the forestry industry [8], in the pharmaceutical sector [9], and in the health care sector [2]. These differences are also specific to an organisation's role in the supply chain (e.g. manufacturer, distributor, transporter, retailer), to the diversity of the products, to their regulatory and business environment, and to their different strategies in terms of costs and benefits [2]. Traceability management involves the association of the information flow with the physical flow of traceable items within and between supply chain facilities (i.e. internal traceability vs. external traceability). The healthcare sector has been calling for product traceability in order (i) to comply with regulatory requirements and guidance on product recall and withdrawal, (ii) comply with supply chain trading partner's specifications, (iii), increase the efficiency of operations such as logistic management and quality management (iv) support patient safety, (v) ensure product authentication, etc.

To ensure traceability, an organisation will leverage an inter-organizational system (IOS) to share information across partner organisations as well as automatic identification and data capture (AIDC) technologies such as barcodes and more recently radio-frequency identification (RFID) to collect and manage traceability data efficiently. Consequently, traceable items require a unique identification to differentiate a specific individual item from all other similar items. Unique identification of items can be driven by different operational (e.g. logistics, acquisition) and financial/accountability requirements to identify and track item information [10]. For example in its "Guideline to Uniquely Identifying Items" [11] the United States Department of Defense (DoD) determined that items meeting the following requirements should be identified uniquely (1) the unit acquisition cost is at least $5,000, or (2) they are DoD serially managed (i.e. need to be uniquely tracked, controlled or managed in maintenance, repair and/or supply by means of its serial number), (3) mission essential (e.g. evaluated in terms of how its failure would affect the ability of the system to perform its intended functions) and (4) controlled inventory (i.e. items having characteristics that require that they be identified, accounted for, segregated, or handled in a special manner to ensure their safeguard and integrity—for accountability, control, and stewardship procedures).

In the health care sector, traceable items are also subject to a similar screening process as they are often subject to a more strict management control in order to reduce the risk of (i) undetected loss, (ii) unexpected shortages which could have a severe impact on operations, and (iii) unnecessary purchases of costly items already on hand. Traceable items may include various classes of objects such as strategic mobile medical equipment (e.g. infusion pumps), specific prescription drugs (e.g. narcotics, expensive drugs) and targeted medical supplies (e.g. consignment and high value products, implantable products, products subject to specific regulations or potential recalls). As we will describe it in this paper, the ability to automatically and uniquely track and trace these items has a direct impact on operational efficiency.

The objective of this paper which focuses on internal traceability processes (i.e. indoor movement, transformation, storage, usage, destruction) is to present a case study of a hospital operating room (OR) that has evaluated an RFID-enabled system for the management of consignment and high value products that require item level traceability. For simplification purposes, these products which include implantable products such as pacemakers, cardioverter-defibrillators or arterial stents will also be named "traceable items".

The paper is organized as follows. The next section briefly highlights the need for the healthcare sector to become more efficient and provides examples of current RFID applications in healthcare with an emphasis on solutions for products that require traceability at the item level. The materials and methods section presents the context of the case study and the process used during data collection. The results are divided in three sections: (i) the hospital's pre-implementation data as collected and analyzed, (ii) the RFID-enabled traceability system for consignment and high value products and, (iii) the forecasted post-implementation impact of the system. The paper concludes with implications and proposed future research avenues.

Literature review

Reducing "waste" in healthcare and improving its efficiency: A global challenge

With an increasing demand for healthcare services, the health system's share of program spending is constantly rising. Unfortunately, this trend is combined with an increasing shortage of doctors, nurses and skilled ancillary personnel, undue work pressure, ineffective communication mechanisms and already existing but unreadily available clinical information [12]. As Porter and Teisberg [13] suggest: *"Health care is on a collision course with patient needs and economic reality"*. Reducing waste in the healthcare system and improving its efficiency is therefore a global challenge, highlighting the need to identify any source of potential improvement and leverage any tools, techniques, methods and technologies to improve healthcare delivery and services around the world. With most of their expenses tied to patient care activities, hospitals can certainly improve their clinical practices while controlling their costs by better managing their labor, supplies, equipment and facilities.

Reducing "waste" in healthcare—a leaner perspective

"Lean thinking", initially introduced in the automobile manufacturing sector [14] consists in eliminating all sources of "waste" while continuously increasing the percentage of "value" to the work [15]. Here, "waste" is defined as any activity that consumes resources without creating value—such as errors leading to product rework, manufacturing of products not responding to customer needs, over stocking, useless process activities, unnecessary employee/product movements, bottlenecks created by inefficiencies in front end activities, etc. The lean concept initially coined "Lean production" and further extended to "Lean enterprise" was publicized in the early nineties by Womack et al. [16], based on their study of the production methods underlying the Toyota Production System (TPS). It has now crossed various sectors and diffused into the healthcare sector—suggesting that "the Toyota way" could lead to healthcare excellence in terms of increased efficiency and quality improvement [15, 17]. In fact, interest in the application of this improvement approach within the healthcare sector has grown significantly in the last few years [18] where activities that do not add value to patient care are now scrutinized. For instance, the Virginia Mason Medical Center in Seattle, Washington, may be one of the most cited examples of a healthcare organization that has reviewed its processes according to lean thinking, and witnessed a dramatic improvement in their operations. Among the researchers that have been studying the adoption of lean concepts (i.e. Kanban, 5S, Jidoka, visual control and Poka yoke) on the optimization of processes related to the delivery of care, Landry and Beaulieu [19] suggest that RFID technology can enhance actual replenishment methods and lead to lean healthcare by combining the two-bin kanban replenishment system with RFID technology—i.e. increase the efficiency of hospital processes and reduce various types of waste such as surplus inventory, expired products, and unnecessary staff movements. Although not formally linked to lean healthcare, similar findings were discussed by Bendavid et al. [20] in a case study of a hospital nursing unit that had evaluated an RFID-enabled two-bin e-kanban replenishment system. The authors explain how important benefits can be derived from time savings that can be transferred to patient care activities combined with a significant reduction of on-hand inventory at distributed storage locations. In fact, among the technological solutions available to increase healthcare efficiency, recent improvements to RFID technology and supporting applications offer a great potential for hospitals that wish to improve their processes.

Reducing "waste" in healthcare and improving its efficiency: A SCM perspective

> *Healthcare costs are rising at an alarming rate. A significant cost driver is the universal complexity of the healthcare supply chain. It is believed that healthcare logistics is an area in which costs can be reduced and efficiencies gained in order to provide healthcare delivery at a reasonable cost (…but) the healthcare supply chain is in its infancy stages* [21 p.3.]

Within the context of this paper Lambert's definition of Supply Chain Management (SCM) will be retained; namely "the integration of business processes from end user through original suppliers that provides products, services, and information that add value for customers" [22]. This definition puts the emphasis on key dimensions that will be explored in this paper, such as business process integration, information flow and value added activities. Although the definition includes suppliers, only the processes at the focal organization level (i.e. the hospital) will be explored in more detail. While a great deal of scientific papers have been written on the impact of RFID technologies on SCM [23], much of the research on RFID in the healthcare supply chain is still very limited, mostly addresses the future potential of the technology and speaks little of RFID actual use in today's healthcare supply chains [24]. Our paper is a partial answer to this gap as it presents an actual case study of RFID-enabled traceability system for consignment and high value products and how this system can improve the efficiency of specific supply chain processes such as logistics processes.

In terms of logistics costs, Chow and Heaver [25] suggest that approximately 46% of an average hospital's operational budget is related to logistics activities. More specifically, this portion of the operational budget is distributed in the following way: 27% for the cost of supplies, 4% for time spent by clinical staff on logistics tasks, and 15% for employees assigned to logistics duties, including material management, but also nutrition and laundry staff. Improving some of these logistics processes could have a great impact in term of reducing operating costs. Similarly, a recent report from the Ontario Buys & Healthcare Supply Network [26] indicates that the logistics function, which in this case, relates precisely to the purchase and supply of goods and services, represents more than 20% of a hospital's total operational budget, accounting for hundreds of millions of dollars per year. More recently, researchers from the Center for Innovation in Healthcare Logistics at the University of Arkansas in conjunction with the Association for Healthcare Resource & Materials Management (AHRMM) administered an industry survey to assess the state of the healthcare supply chain from a cost and quality perspective [21]. The authors mention that 31% of healthcare provider's annual operating costs is being spent to support the supply chain—where healthcare supply costs are incurred primarily to support inventory and order management. The fact that hospitals have not yet taken advantage of supply chain opportunities [27] suggests that financial priorities and project portfolio management should be re-evaluated. Given the impact of these costs on the overall operating budget, the constantly growing expenses due to the increasing cost and use of supplies, and the limited automation solutions normally in place, a potential exists for significant cost savings. One untapped way of reducing operating expenses is for hospitals to address supply chain management inefficiencies by leveraging automatic data capture technologies and supply chain automation solutions. When looking at specific product categories, consignment and high value products may represent an interesting niche for such improvement. On average, 65% of a hospital's acute care medical supply costs are concentrated within three departments, namely catheterization laboratories, interventional radiology and the operating room, where 5% of the total number of items account for 50% of the total supply costs and 85% of the total chargeable value of the supplies [28]. The hospital system under study reported that the supply costs of the three aforementioned departments represent 79% of its overall medical supplies budget.

RFID applications in healthcare

The healthcare sector is positioned as a strong emerging market for RFID as RFID tags and systems are expected to rise rapidly from $94.6 million in 2009 to $1.43 billion in 2019 [29]. This increase is primarily due to maturing of applications such as the Real Time Locating System (RTLS) for asset, medical staff and patient tracking. RFID initiatives targeting item level tagging of RX drugs and medical disposables are also driving the adoption. Of note, the tagging of blister packs and plastic bottles used by patients is primarily a US phenomenon, driven by the need for improved anti-counterfeiting, but also for theft deterrence, improved stock control and enhanced product recalls.

RFID is still a relatively young market with good growth potential. Still, the overall picture of RFID in healthcare is nuanced as healthcare providers *"do not care about the technology, but about costs and functionalities"*—meaning the applications that can be improved with RFID technologies [30] p13]. The authors also suggest that RFID applications found in hospitals mainly focus on logistics and operational management, with different adoption perspectives from the US (driving cost reductions) and Europe (focusing on quality of care). Although conflicting, as presented in this study, we do think that these two views are not necessarily incompatible. More specifically six areas of RFID applications are clearly emerging in the healthcare sector to enable a safe and secure healthcare supply chain [31], namely: (i) IT and Medical Asset Management, (ii) security and access control, (iii) patient safety and management, (iv) employee management, (v) supply chain management & condition monitoring, and (vi) toxic waste management. Although RFID shows tremendous potential to enhance the efficiency of the healthcare medical supply chain [32], in this industry, it is an often-neglected activity which deserves much more attention [27].

RFID-enabled cabinets & smart shelves

In order to manage high-value products, several hospitals are adopting RFID-enabled real-time inventory management systems such as RFID cabinets or "smart" shelves. Companies like *Wavemark, Mobile Aspects, Stanley InnerSpace, Terso Solutions CareFusion and Omnicell* offer such products to help organizations control inventories and keep products in continuous stock [33]. Basically, each cabinet is equipped with a reader and accompanying software that records each transaction such as what was removed, when it was removed, who removed it and (eventually) for which patient the product is intended. Some solutions also include an application for collecting data from RFID personnel identity cards before providing access to the storage cabinet. When integrated with the Hospital Information System (HIS), captured real-time data can feed the clinical documentation system, improve expiration date and recall management and eliminate the need to maintain excess inventory because staff know exactly how many high value products are available in the hospital.

Materials and methods

The case study at hand presents a passive HF RFID-enabled traceability system for the consignment of high value products with simpler and lighter technological requirements than the alternative RFID-enabled cabinets and smart shelves. It consists of capturing the product data at the point of entry and at the point of consumption thereby assuming the availability of the supplies in between points. The innovativeness of the RFID system presented in this paper is not based on the technology itself, but rather from its use to support an improved healthcare supply chain process.

While the following case study is presented in a closed-loop context (within one room of one hospital), suppliers can be included in the replenishment process when the HIS is linked to an inter-organizational system (IOS) in order to automate Electronic Data Interchange (EDI) which enables electronic document interchange between healthcare supply chain members.

Research design

As a result of the scarce RFID literature pertaining to (i) supply chain management in the healthcare sector [24], particularly with regards to consignment and high value products, and (ii) the importance of traceability issues, particularly with regards to implantable products, there is a need to better understand how an RFID system can contribute to the way healthcare institutions improve the management of their supply chain processes. The prime motivation for this research was therefore to contribute to this literature and provide an indication for practitioners on how to evaluate such systems. Since RFID-enabled supply chain management in the healthcare context is an emerging, complex and multidimensional phenomenon (i.e. multiple stakeholders, technologies, products and impact), the case study approach was selected in order to facilitate the identification of the main concepts involved [34].

The case study

The case study is based on empirical evidence collected from a clinical department of a public 246-bed Canadian hospital: the Hôtel-Dieu Hospital. In October 1996, the focal hospital (Hôtel-Dieu) merged with two other hospitals (Hôpital Notre-Dame and Hôpital Saint-Luc) to become the hospital system called the Centre Hospitalier de l'Université de Montréal (CHUM). The CHUM, a 1,200-bed hospital, treats an average of one million patients each year, including 115,000 patients in its emergency departments and more than 450,000 patients in its outpatient clinics. It employs over 10,000 employees, including 900 doctors and 270 researchers. 6,000 students and interns and 700 volunteers complete the team. Some 35,000 surgeries are performed at the CHUM. In 2009 8,700 surgeries were conducted at the Hôtel-Dieu operating rooms, where general surgery accounted for 18% of all surgeries, cardiac surgeries 17%, ophthalmology 15%, plastic surgery 12%, orthopedic 11%, otolaryngology 9%, vascular surgery 7%, 11% were various other procedures.

This case study was conducted within a wider initiative that lasted six months and consisted of improving the operating room supply chain. The analysis of the traceability processes for consignment and high value products was conducted in five specific phases:

1. The initial phase was initiated through the development of a formal relationship with the healthcare institution. A team of stakeholders supported by a consulting team was put in place with the mandate to define the project's requirements, clarify its scope and identify the data collection and analysis tools required to assess the supply chain processes.
2. The second phase corresponded to the research project's startup activities, which included the creation of an internal coordination project committee whose mandate was to coordinate the research activities and support the team for any further data gathering and analysis. This committee included staff from the operating room, sterilization, material management and administration. These key stakeholders were consulted throughout all the phases of the project. Additionally, the results were presented to hospital management for approval.
3. The third phase consisted of statistical data collection, interviews and on-site observations. One of the objectives was to document the replenishment process for consignment and high value products and determine its associated costs. Respondents then validated the process flow charts and costs.
4. Improvement opportunities and traceability issues were then identified and evaluated in the next phase by assessing selected processes. A process-based approach was selected, as it provides a cross-functional vision of

supply chain processes rather than one that is fragmented by department. This perspective enabled the team to assess the potential impact of the redesigned processes on the entire supply chain to be optimized rather than delivering a series of local improvements. One of the main objectives for the improvement opportunities focused on freeing up nursing staff from non-value added activities. Given the current and projected shortage of nursing personnel within the healthcare sector, a major portion of logistics activities currently performed by nursing staff were transferred to support staff such as store personnel. The final area of interest for the consulting team was to identify a means by which inventory and replenishment costs could be reduced without compromising the quality of care, e.g. holding enough stock to ensure efficient service delivery.

5. Lastly, the potential benefits of increasing the traceability of selected products and redesigning portions of the replenishment process through the use of an RFID system were estimated by combining business process analysis, time and motion studies and Activity-Based Costing (ABC) analysis. The RFID-enabled scenario was then validated with the institution and its impact estimated.

Data collection and analysis

Data collection is based on both qualitative and quantitative data that were collected using semi-structured interviews, on-site observations, experience from previous implementations, as well as validation observations of a similar solution implemented in the Hôtel-Dieu catheterization laboratory. Key respondents validated the data and estimates presented in this paper, thereby increasing their reliability.

1. Using a questionnaire, semi-structured interviews were conducted concerning the operating room under study with department managers involved in the research process. This step helped to (i) establish an overview of how the department functions; (ii) define the issues and identify particular problems; (iii) validate and facilitate the data gathering sequence by identifying key individuals involved in the activities under study; and (iv) prepare the team for the on-site gathering of information on topics such as product traceability (i.e. capacity to track and trace, track and match), shrinkage issues, involvement of hospital staff in the process, etc.
2. On-site observations were conducted in the healthcare institution with the main objective of mapping and assessing the "as-is" replenishment/traceability processes. At this step, a sample of key personnel (1 storekeeper, 2 administrative clerks, 6 nursing staff, 1 perfusionist, 1 buyer and 1 administrative technician) was selected and observed during an equivalent of seven days over two months. Although the process under study included activities from the purchasing department, the researchers decided to ignore the time included in these activities (and their potential savings) because it is difficult to clearly discriminate purchasing activities associated with non-stock vs. consignment/high value products. Thus the estimates will be more conservative.
3. In order to better understand specific aspects of the processes, and properly estimate the proportion of each activity for a given process, during the observation period, key personnel performing the activities under study were asked questions such as:

   - How are you notified if a product that requires traceability is consumed?
   - How do you evaluate the needs for product X and complete order requests?
   - What is the replenishment frequency for product X? Each time a product is consumed?
   - In a regular week, how much time do you estimate you spend checking and sorting delivered products?

   More general questions were also asked, such as:

   - Do you have any comments on the replenishment process for consignment and high value products within your department?

The main idea was to follow the processes, identify the key personnel involved at each step, and gather information relative to the processes. Various information sources were available to help the team understand the processes and evaluate their costs. These included: (i) meetings with the managers of the departments involved in this study; (ii) statistical data provided by the institution; (iii) interviews with personnel involved in the processes targeted by this study; (iv) observation of the physical sites; (v) observation of the work of the people involved in the processes; (vi) documents used in the processes under study; and (vii) as required, additional information from hospital files and surveys.

Using a discrete, non-intrusive data capture approach, a data log analysis (replenishment transaction lines in the hospital's information system/ERP) and a time and motion study were also performed to gather quantitative information. A similar approach to the time-driven activity-based costing analysis approach [35] was adopted to perform the analysis. The approach was based mainly on two parameters:

- the "unit cost of supplying capacity," meaning the committed resources and their cost;
- the time required to perform the replenishment/traceability activity.

These parameters were used to combine resource expenses (resource cost drivers), statistics on the frequency of activities (transactional cost drivers) and the results of the time and motion study (duration cost drivers) for each role (nursing staff, administrative staff, store personnel, etc.) involved in the process under investigation in order to determine process costs. The selection of this method was motivated by the need to identify cost centers and assign them to specific activities and processes.

The next step was to validate the mapped processes and their related costs. This was achieved by building draft flow charts and associated cost time tables and presenting them to key respondents in the hospital (i.e. draft versions of the figures and tables presented in this paper). Other types of documents used at this step included the definition of a formalism to support the analysis of logistics processes (e.g. color coding by department, symbols by activity type, etc.), analysis of operational performance and allocation of resources (time analysis), assessment of necessary resources, etc. Finally, for the management of consignment and high value items, an RFID-enabled scenario was proposed, and its impact on process performance and traceability improvement was estimated based on:

- data gathered in the previous steps
- time and motion estimated savings from implementing an RFID-enabled traceability system
- shrinkage estimates

4. Experience from a similar implementation at the Hôtel-Dieu catheterization laboratory (another clinical department where the solution had already been deployed) allowed to refine the estimated gains for the operating room thereby increasing the reliability of the estimated results. All of the results were presented to key respondents for validation to ensure that the estimates were realistic. It is important to note that a full assessment is required at each new site where the system is to be implemented, as variables such as current IT infrastructure, initial storage layout, type of shelving, percentage of traceable items used, etc., will have a direct impact on the redesigned processes and proposed technological solution.

Pre-implementation data

Cost assessment for medical & surgical product management

Table 1 presents a summary of the data gathered concerning the annual costs of medical and surgical product management at the focal hospital level (Hôtel-Dieu) and at the hospital system level (CHUM). Three main categories of products are presented, namely: stock items, non-stock items and consignment items which are often traceable items. Consignment items are products owned by the supplier until their consumption while implies that product charging occurs only after the hospital has used the product. When looking at all product categories at the focal hospital, these account for 3,553 different SKUs (stock keeping units), which represent a total annual consumption value of $7,279,990. For these products, the compound number of requisition lines equals 18,735 (i.e. number of times a SKU was ordered).

- **Stock items** are composed of medical supplies stored in a facility's central store and replenished upon request at different storage locations situated at point of use distributed throughout the facility. These items represent 7% of the annual total value of the products used in the operating rooms of the focal hospital (i.e. $520,334), and are composed of 419 different SKUs.
- **Non-stock items** are sourced externally. Orders are prepared by the vendor to fill the specific user department needs and are stored in the user department, whether the operating room, catheterization laboratory, interventional radiology, nursing units, etc. These items represent $4,505,535 or 62% of the annual total value of the products used in the focal hospital's operating room and are composed of 2,142 different SKUs.

Finally, **items requiring traceability at the unit level** are typically high value items, not exclusively but often managed as consignment inventory (e.g. heart valves, breast implants, hip or knee prostheses, etc.) and are often replenished on a unitary basis. They represent $2,254,121 or 31% of the annual total value of the products used in the focal hospital's operating room and are composed of 992 different SKUs. Looking at the initial replenishment process for items requiring traceability (Fig. 1), which includes the administrative and physical activities, it is interesting to note that this process was essentially performed manually by gathering package labels from consumed products and managing the implant order sheet. In terms of estimated cost, this represents $36,270 per year (or 1360 h per year, as detailed in Table 2) or an average of $10.32 per transaction (i.e. obtained when divided by the number of requisition lines). Within the hospital system (CHUM), items requiring traceability represent 2,196 SKU, or 20% of the annual total value of the products used in the operating room and are valued at $4,570,608. With 9,407 requisition lines, the cost per "logistic process" was estimated at $68,867 per year.

Table 1 Annual costs associated with medical/clinical product management

Service	Product Category	No. of SKU	No. of requisition lines	Value of products ($)	Value of products (%)	Cost per process ($)	Average cost per line ($)
Operating Room (Hôtel-Dieu)	Stock items	419	6,239	520,334	7%	N/A	N/A
Operating Room (Hôtel-Dieu)	Non stock items	2,142	8,982	4,505,535	62%	N/A	N/A
Operating Room (Hôtel-Dieu)	Consignment items	992	3,514	2,254,121	31%	36,270	$10.32
Sub-total Medical and surgical products (Hôtel-Dieu)		3,553	18,735	7,279,990	100%		
Operating Room (CHUM)	Consignment items	2,196	9,407	4,570,608		68,867	

In addition to the costs associated with the replenishment of medical and surgical supplies, other reasons motivated the choice of examining the replenishment process for items requiring traceability:

- The high value generally associated with these items, which constitute considerable capital locked up in inventory and the risks related to financial exposure, both from a manufacturer's and a user's perspective. For example, a mechanical aortic valve can cost up to $5,000 while a defibrillator can reach $25,000.
- A large number of these items are implantable and therefore require clinical traceability. As such, hospitals must be able to efficiently manage a recall process by rapidly tracing products and matching them with patients.
- Charge capture management is required when high value items must be invoiced by the healthcare facility to insurance companies in the US due to the private reimbursement system. Charge capture is also anticipated to be implemented in Canada for cost control purposes.

Current replenishment process for traceable items

Figure 1 presents the "as is" replenishment process for traceable items in the operating room at the focal hospital. When looking at the initial replenishment process, logistic activities can be categorized in terms of administrative and physical activities conducted by numerous players: nursing staff, perfusionists, administrative clerks, and store personnel.

For each specialty (e.g. general surgery, cardiology, ophthalmology, etc.), any time an item is used for a specific procedure, a label inserted by the manufacturer in the package is removed and applied by the nursing staff to a sticker sheet (also called an implant order sheet), which indicates the consumption of a specific product. This event triggers the replenishment process. On a regular basis the sticker sheet is brought to the administrative clerk for data entry in the system (i.e. completing an Excel spreadsheet). The files are then used to consolidate consumption data and execute an electronic requisition by referring to the lot and serial numbers of each item. This action triggers the purchasing process, which leads to product delivery by the suppliers.

Upon receipt of the supplies, traceable items are verified three times: firstly, a storekeeper matches the packing slip from the bill of lading with the products received and enters receipt of the product into the ERP system. Secondly, once the product is brought to the operating room, the administrative clerk performs a second verification, including a check of the package contents. Items are then put away in their appropriate storage locations. Finally, the chief of the specialty or perfusionist verifies the reconciliation of the products received and consumed. As mentioned above, in terms of transaction costs, this represents an estimated 1,360 h per year (see detail in Table 2) or an average of $10.32 per transaction (Table 1).

Analysis of the current replenishment process for traceable items

The replenishment process is essentially done manually. It is important to note that most North American hospitals still manage consignment and high value items with paper based systems and that the process observed at this site is in line with most hospitals where consignment and high value items are managed manually.

As presented in Fig. 1, multiple stakeholders from different departments (operating room, purchasing, receiving and stores) are involved in the replenishment cycle. The process is therefore time-consuming for administrative clerks and but also nursing staff, who spend valuable time on non-value-added activities, such as filling and managing implant sheets, filling order requests, tracking orders, completing, faxing and filing purchase orders, etc. The observation also highlighted the fact that store personnel, who should be highly involved in material management activities, were in fact spending less time on the replenishment process that their colleagues.

It can be observed that the process is essentially paper-based, where each actor relies on various documents during the replenishment cycle to perform his or her activities. This process is inefficient, particularly when one considers the proportion of the process related to the communication

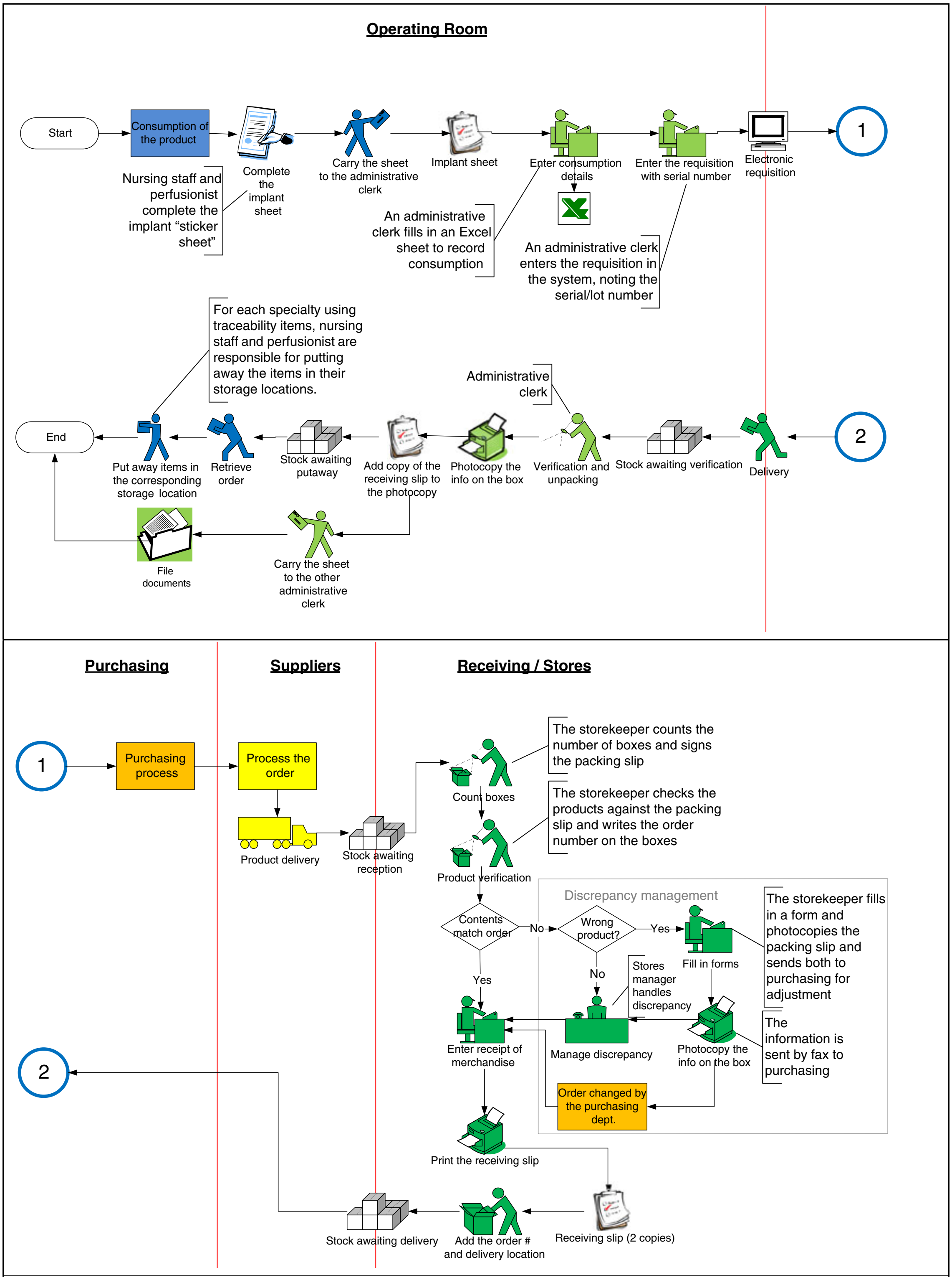


Fig. 1 Replenishment process for traceable items

of information between the moment the consignment products are used in a surgical procedure and the moment the information is communicated to the supplier. As presented in Fig. 1, the implant sheet is the means to collect and share the information on consumed products. Aside from multiple time delays, this process is also prone to errors resulting from sticker loss or data transcription errors during the replenishment process.

Table 2 Summary of RFID-enabled traceability item forecasted impact on the replenishment process

Description	Details	Current cost/year (hours)	Current cost/year ($)	Savings / one year (hours)	Savings / one year ($)	Savings / five years ($)	Forecasted cost/year (hours)	Forecasted cost/year ($)
Recurring time savings								
Productivity gains from logistics processes	Nursing staff	304	10,605	278	9,699	48,497	26	906
	Perfusionist	62	1,890	62	1,890	9,452	0	0
	Administrative clerk	884	21,201	884	21,201	106,007	0	0
	Store personnel	110	2,573	−315	−7,404	−37,019	425	9,977
Sub-total (recurring time savings)		1,360	36,270	910	25,388	126,938	450	10,883
Inventory shrinkage (3%of annual value of items distributed)	Traceability items				67,624	338,118		
Sub-total (inventory shrinkage savings)					67,624	338,118		
Sub-total of recurring time and inventory shrinkage-related savings					93,011	465,056		
Non-recurring inventory-related savings								
Optimization of inventory levels	Traceability items				N/A	N/A		
Sub-total - non-recurring inventory-related savings					N/A	N/A		
Total					93,011	465,056		

The nursing staff was spending 304 h replenishing traceable items: completing the implant sheet (114), putting away the products in the OR (178), tracking orders (13); perfusionists 62 h: completing the implant sheet (4), filling in order requests (4), completing, faxing and classifying purchase orders (26), tracking orders (26), putting away the products in the OR (2); administrative clerks 884 h: filling order requests (520), tracking orders (208), verifying and sorting products at the (130), filling in, faxing and filing purchase orders (26); and finally stores personnel 110 h: verifying the receipt of products (37), entering data related to product receipt (21), managing orders (52); for a total of 1,360 h.

Various information system applications are used to support the replenishment process. For instance, data from implant order sheets are gathered by administrative clerks using Excel files and then transferred to the supplier using an electronic requisition system.

Although not illustrated at the end of the process on Fig. 1, other issues related to storage management were identified during the on-site observations. For instance, as nursing staff put items away in their respective storage locations, certain information issues (i.e. incomplete information about the storage location, non standardized or outdated information, different product codes registered in the hospital's ERP, etc.) rendered the task more difficult. Also, the design of the storage locations (including storage shelves) were also found to be inappropriate to ensure efficient product management, contributing to inventory shrinkage issues due to the difficulty of ensuring correct inventory turnover and thereby contributing to an increase in the number of expired products or the potential consumption of expired products.

Through the process mapping exercise, the team found that because product expiration management of the operating room was essentially a manual task (i.e. without the support of a material management tool), the personnel relied on their own knowledge and personal experience to make replenishment decisions and evaluate the quota of products to be reordered. This situation also contributed to issues such as (i) increased quantity of products kept in inventory; (ii) inventory shortages; (iii) more expired products; and (iv) inefficient processes for tracking consumed products.

The RFID-enabled traceability system

Traceable consignment and high value products need to be uniquely identified to allow traceability and as such lend themselves to perpetual inventory mode. In order to allow end-to-end traceability, each product transaction (e.g. receiving, storage, consumption, and disposal) needs to be captured and associated to its unique ID. By leveraging its wireless automatic identification and data capture (AIDC) features, RFID technology can facilitate product tracking of the products and conciliation with suppliers through a notice of consumption.

Although replenishment solutions for high value supplies, including but not limited to consignment items in operating rooms, cardiac catheterization laboratories and interventional radiology, can be managed with RFID-enabled cabinets, other methods can fulfill the same purpose while limiting infrastructure costs (of cabinets, for example) by enhancing end-to-end traceability of medical products in the healthcare supply chain.

The case study presents a passive HF RFID-enabled system that functions as a material management system for the items in scope (i.e. supplies that require traceability at an item level such as high value and consignment items). While the following study is presented in a closed-loop context, the replenishment model could automatically include the supplier when the HIS is linked to an inter-organizational system.

RFID-enabled receptacle for the management of traceable items

The RFID-enabled system is shown in Fig. 2 and is composed of:

- Mobile hybrid RFID/bar code reader
- RFID printer
- Tags affixed to consignment/high value item packages
- RFID boards
- A reader and its antenna embedded inside a receptacle to automatically initiate data collection as a package is disposed of during a surgical procedure
- A middleware system that analyzes the data and, based on defined business rules, transmits the replenishment order to the hospital's ERP.

The RFID-enabled process for consignment and high value items functions as follows (Fig. 2):

(a) Once a product is received, the store employees scan the manufacturer's barcode on the package to capture related information on the delivered product (e.g. manufacturer's product number, serial or lot number, expiry date). The captured data is transferred to the middleware in real time to retrieve specific information such as the internal product number, internal product description, requesting department/specialty, and the specific storage location where the product needs to be put away. (b) An RFID printer automatically prints a removable self-adhesive label that contains a unique RFID transponder. The information contained on the initial label (i.e. information encoded on the bar code from the supplier) is associated to the HF RFID Tag Identifier (TID) in a database before the corresponding put away location is assigned. Relevant product information is also printed on the label, including its storage location. (c) The RFID label is then affixed to the product packaging. (d) When delivered to the user department, the product is swiped in front of the RFID board (antenna) to update the application database. This action records the time that the product was delivered to the user

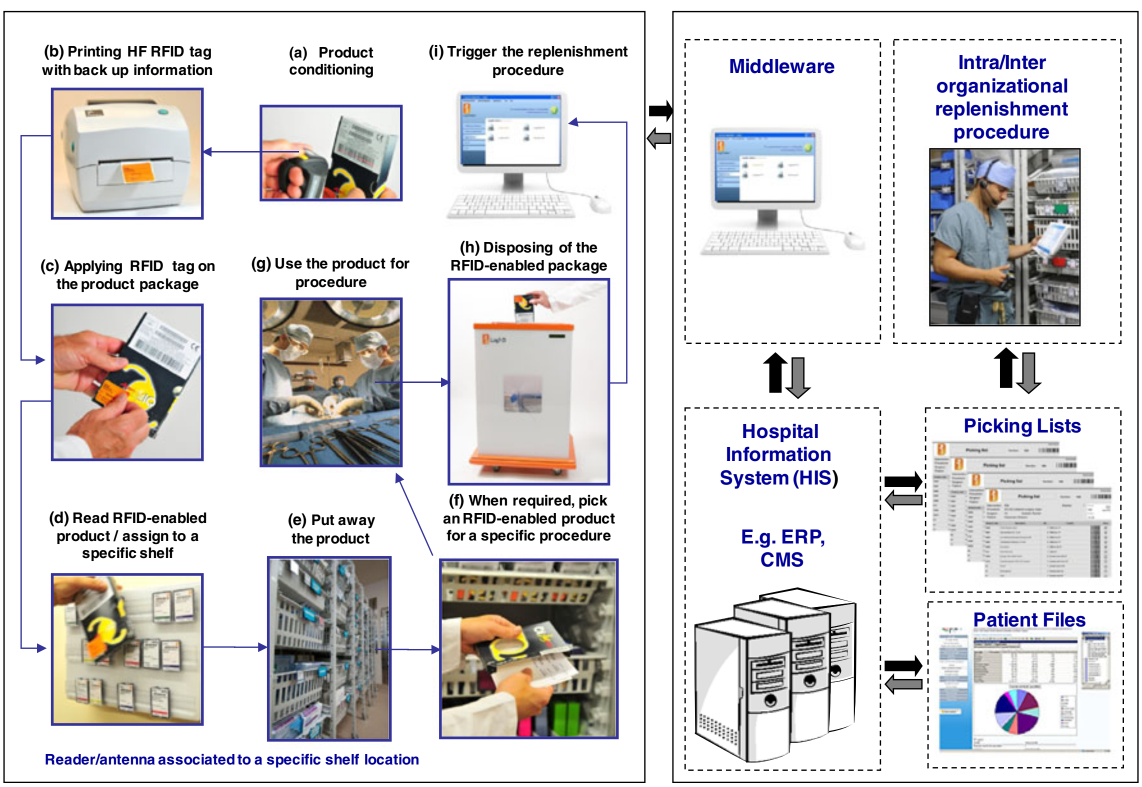


Fig. 2 RFID-enabled solution for the management of traceable items

department and confirms that it is ready for use. (e) The product is then put away in a specific storage location—for instance, storage location W, shelf X, level Y, bin Z. (f) When the product is required for a specific procedure, the product is picked and (g) given to the doctor to be used. (h) The empty RFID-enabled package is then disposed of in the RFID-enabled receptacle directly located in the procedure room, with the product ID recorded in the RFID label automatically captured and transmitted to the middleware hosted by the HIS. (i) This registration automatically creates a replenishment request transaction. In order to ensure tracking and matching between the product, the patient, and the surgical procedure, the information captured by the receptacle can be transferred to the clinical management software (CMS) application and provide clinicians (and administrative staff) with all of the required information for updating the patient file or for charge capture (i.e. billing application). When an empty package is subsequently disposed of in the RFID-enabled receptacle, the process is repeated and consistently provides real time management of consumption of supplies related to specific procedures.

Forecasted post-implementation data

Redesigned replenishment/traceability process

Figure 3 presents the redesigned replenishment process for traceable items in the operating room. Once the purchasing process is triggered, the products are delivered by the suppliers on a regular basis, according to the type of products involved. Upon receipt of the supplies, traceable items are subject to a similar verification (as in the initial process) by the storekeeper, as the packages are not tagged yet with RFID labels. Within the redesigned process, a conditioning step is added before items are put away in their corresponding locations, self-adhesive (smart) labels containing RFID transponders are affixed to the product packaging, initiating the traceability process. Within this process, it is important to understand that the marginal contribution of using RFID technology does not rely on the possibility to uniquely identify the products (which could also be done using some bar code (e.g. GS1-DataMatrix 2D, GS1-128) encoded with a Serialized Global Trade Identification Number—SGTIN) but from the automation in the data capture which is particularly interesting in hospital specialized care units (e.g. OR, catheterization lab) where the priority is not on product replenishment but on the patient. Indeed, in such stressful working environments where a scan can be easily omitted, the implication of the medical staff in the product disposal/replenishment process has to be minimized, ideally to no human intervention. Indeed, when looking at the redesigned process integrating an RFID-enabled replenishment system, an important portion of the process is simplified as some logistic activities are automated. For instance, instead of using sticker sheets to capture data on consumed products, any time an item is used for a specific procedure and its empty

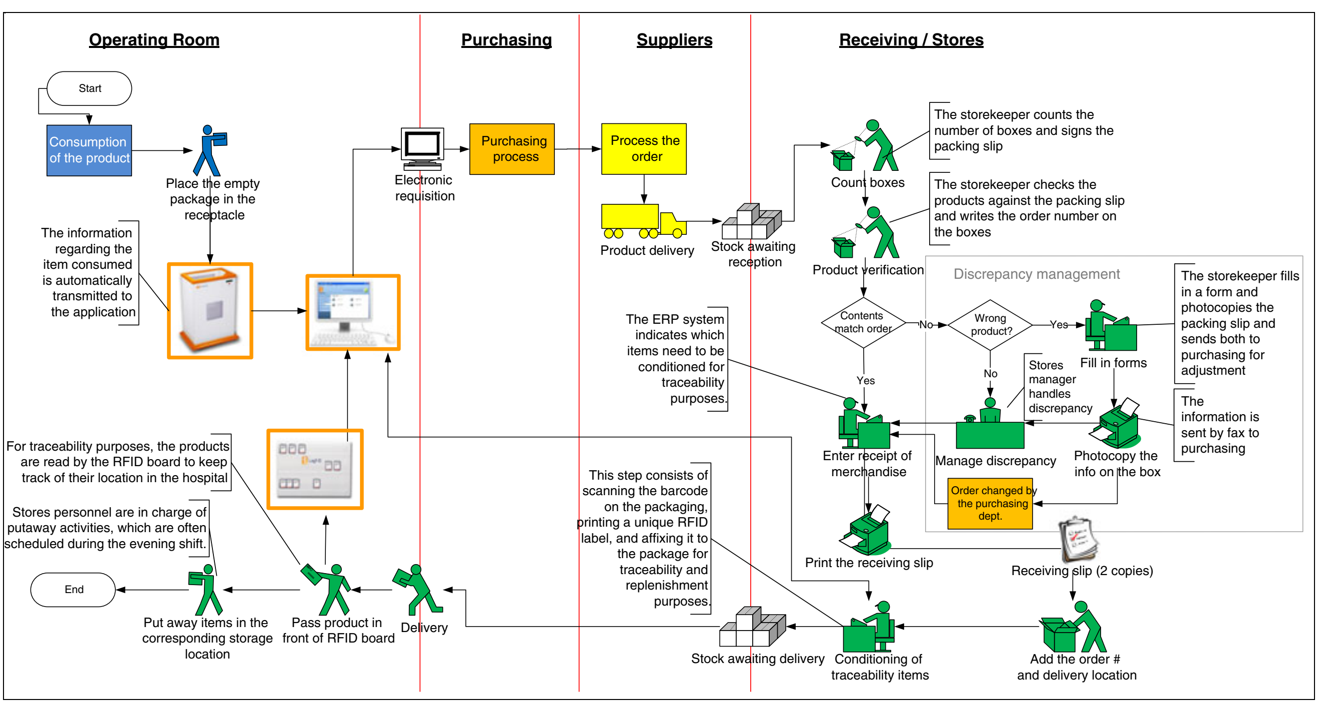


Fig. 3 Redesigned replenishment process for consignment and high value items with RFID-enabled system

RFID-enabled package is disposed of in the RFID-enabled receptacle in the procedure room, the replenishment process will be triggered by automatically transferring the captured information to the inventory management application hosted on the HIS (see Fig. 2). The automation of this process has a direct impact on the administrative clerks, who are no longer involved in the process. The electronic requisition order is now completely automated, freeing the purchasing department of non-value-added activities such as data gathering, filling in order requests, completing, faxing and filing paper requisitions, etc.

ROI for RFID-enabled traceability system at the Hôtel-dieu

Although cost and ROI are the biggest concerns regarding the implementation of RFID [24] the literature on this subject is limited [23]. And while a wealth of research has considered the benefits associated with organizational innovation (such as RFID), costs have received much less attention [36]. To address this gap, recent work has been conducted such as the customization of existing frameworks for examining related costs and benefits derived from RFID implementation [23, 36–38]. Accordingly, while RFID is relatively new to the market, the various types of costs to take into account when building a ROI are similar to IT/IOS innovation project and occur at different stages of the adoption process. As Bahri [39] points out: beside contextual differences, RFID managers in hospitals need to be aware that the technology's implementation is no different than that of other types of information systems. Within this paper, the costs relate to the implementation phase which generally includes costs associated with acquiring and implementing the solution such as (i) hardware costs, (ii) software costs, (iii) system integration/installation costs, and (iv) costs derived from Business Process Reengineering (BPR). Hence, a conservative ROI for the RFID-enabled Traceability system was estimated by the technology supplier at a little over 2.3 years. This time frame was estimated by taking into account:

(i) The cost of the solution which includes fixed costs for RFID receptacles (one receptacle per operating room), RFID readers, antennas and boards (one in each operating room), RFID HF labels (related to the number of items consumed per year, with an average of 3,500 items), (ii) the middleware system, licenses, (iii) and estimated costs for the labor required for system integration; and (iv) comparing them with the savings presented in Table 2. The savings presented in Table 2 are estimated over a five-year period as the provincial health and social service agencies use this metric to evaluate projects. As the goal of the paper is more to provide an approach for researchers and practitioners to assess the potential impact of an RFID-enabled system for traceable items, the discussion on ROI analysis was simplified. For instance, while the Net Present Value (NPV) should be used to analyze the profitability of the project and ensure a greater accuracy of the potential savings (i.e. taking into account the RFID project initial costs, operational costs, and expected cash flows/savings), calculations factors such as inflation and discount rates were not taken into accounts here.

Impact of the redesigned replenishment/traceability process

During the case study, the gains were calculated only on consignment items, thus potential gains resulting from the implementation of the receptacle will undoubtedly be superior once the system is deployed in the OR for all traceable items. Three main categories of savings derived from the redesign of the replenishment process are presented, namely: (i) productivity gains for logistics processes, (ii) inventory shrinkage, and (iii) non-recurring inventory-related savings. As can be observed in Table 2, which presents a summary of the estimated impact of the RFID-enabled traceable item replenishment process ("forecasted") at the focal hospital (Hôtel-Dieu), the replenishment process improvements are associated with the nursing staff and administrative clerks. Respectively, these gains were estimated at 278 working hours valued at $9,699 and 884 working hours valued at $21,201 for the first year. Although these overall potential productivity gains can represent "hard savings" if they are transformed into full-time equivalent reductions (i.e. actual jobs) they do not represent the most important portion of the savings. On the other hand, these time savings, especially for nursing staff, can have a direct impact on patient care, as nursing freed-up time will be re-directed to treat patients instead of being assigned to material management tasks [20, 40]. In terms of transaction costs, the new process requires an estimated 450 h per year representing time savings of 910 h per year or an average of $3.10 per transaction (10,883$/3,514 lines as seen in Table 3). This represents a 70% reduction in transaction cost.

Table 3 As-is vs. forecasted costs associated with consignment item management

Service	Product category	No. of requisition lines	"As-is" cost/year ($)	Forecasted cost/year ($)	"As-is" average cost per line ($)	Forecasted average cost per line ($)
Operating Room (Hôtel-Dieu)	Consignment items	3,514	36,270	10,833	$10.32	$3.10

The proposed solution eliminates manual requisitions, transcribing and re-transcribing data, along with its associated errors, as data capture for consumed products is fully automated. On the other hand, as the processes are redesigned, a greater scope of material management responsibilities is now transferred to store personnel. For example, store personnel are now completely in charge of verifying and sorting products and for putting away the products in the operating room. This accounts for an additional cost of $7,404 in the form of 315 additional hours.

Inventory shrinkage deserves special emphasis, as it represents a particularly challenging aspect of inventory management, especially for consignment and high value products, as a small discrepancy can rapidly become costly. In the context of this study, inventory shrinkage can be caused by (i) the lack of accuracy of information on stored products (ii) replacement of products with new products, (iii) products no longer used after a surgeon and/or anesthesiologist has left the hospital, or (iv) unused products in the operating room.

The shrinkage ratio can be assessed by using various factors, including:

- the evaluation of the global value of product loss based on the value of a hospital's on-hand inventory for this category of products and the level of efficiency of its replenishment processes,
- the number of expired products,

Expired products and related inventory shrinkage issues are also of particular interest to suppliers of consigned products, who are sometimes ready to finance the traceability solution. In fact, the most significant financial gains derived in part from risk avoidance may be at the supplier level, considering the volume of products they have in multiple locations and the fact that they own the inventory until it is consumed.

Finally, when looking at non-recurring inventory savings, the quantifiable benefits gained from the optimization of inventory levels are based on the improved visibility of consumption offered by the RFID-enabled replenishment system. This helps provide better control over ordered quantities while optimizing inventory levels, also reducing the number of expired items. Although quantifiable, the gains from inventory reduction were not included in Table 2 because consignment products are not immediately bought by the hospital; they belong to the suppliers until their use. Reducing the inventory levels would therefore not affect the working capital of the hospital, but at the supplier level this reduction has a major impact.

Another important factor for this category of products is that the potential reduction of inventory is limited by the required diversity of products (and product sizes) needed for each type of procedure. For example, different sizes of knee prostheses would have to be kept in inventory to ensure the availability of the product, as requirements cannot be specifically anticipated before the procedure begins.

Although not quantified, other categories of savings linked to the redesign of the process and the adoption of an RFID-enabled traceability system were identified. By automating the data capture of consumed products and transferring them to the clinical management system, clinicians (and administrative staff) would be provided with all of the required information for updating the patient file or for charge capture (i.e. billing application), while ensuring the traceability process.

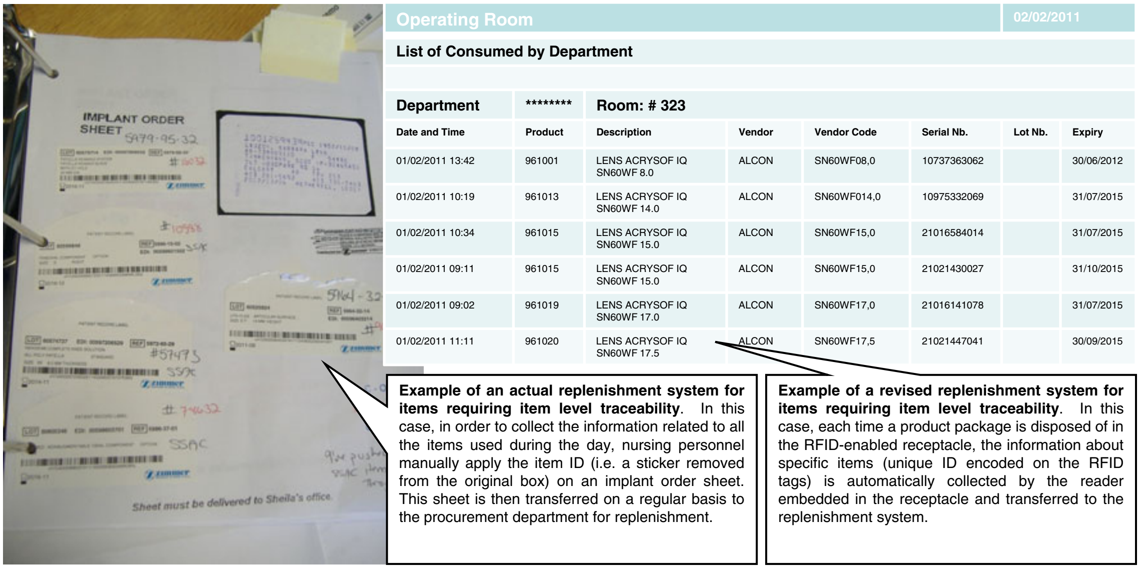
Also, by automating the electronic requisition order and freeing up the purchasing department of non-value-added activities, purchasing department staff can now concentrate on more important activities, such as looking for and evaluating new suppliers or negotiating contracts. And, by having real time data on consumed products, purchasing departments and suppliers can respond rapidly and more efficiently to user departments, thereby increasing the level of service while reducing the probability of errors in the replenishment process.

Improved output reporting

In the current replenishment process a nurse removes the packaging label from the product and applies it to the implant order sheet to indicate the consumption of a traceable item. The image on the left of Fig. 4 is an implant order sheet and is presented to illustrate the manual and paper-based process that is involved. This sheet is brought to a clerk where the time consuming retyping of the sticker information into the system is naturally error-prone and can thus be the cause of costly erroneous data entries. The current replenishment process is a discrete event and inefficient activity that strongly contrasts with the redesigned replenishment process illustrated by the print screen positioned on the right side of Fig. 4 that automatically generates an output in real-time. Its automatic collection of the information represents the ideal optimized process as it reduces the number of people involved, requires no re-entry of information and can trigger the replenishment order instantaneously if the supplier is connected to the hospital's ERP. Additionally, since the lot or serial numbers of each item are collected directly at the time of consumption, the redesigned replenishment process greatly reduces the potential loss of information inherent to a paper based system.

Conclusion

This paper provides an approach for researchers and practitioners alike to assess qualitatively and quantitatively



Operating Room 02/02/2011

List of Consumed by Department

Department	********	Room: # 323					
Date and Time	Product	Description	Vendor	Vendor Code	Serial Nb.	Lot Nb.	Expiry
01/02/2011 13:42	961001	LENS ACRYSOF IQ SN60WF 8.0	ALCON	SN60WF08,0	10737363062		30/06/2012
01/02/2011 10:19	961013	LENS ACRYSOF IQ SN60WF 14.0	ALCON	SN60WF014,0	10975332069		31/07/2015
01/02/2011 10:34	961015	LENS ACRYSOF IQ SN60WF 15.0	ALCON	SN60WF15,0	21016584014		31/07/2015
01/02/2011 09:11	961015	LENS ACRYSOF IQ SN60WF 15.0	ALCON	SN60WF15,0	21021430027		31/10/2015
01/02/2011 09:02	961019	LENS ACRYSOF IQ SN60WF 17.0	ALCON	SN60WF17,0	21016141078		31/07/2015
01/02/2011 11:11	961020	LENS ACRYSOF IQ SN60WF 17.5	ALCON	SN60WF17,5	21021447041		30/09/2015

Example of an actual replenishment system for items requiring item level traceability. In this case, in order to collect the information related to all the items used during the day, nursing personnel manually apply the item ID (i.e. a sticker removed from the original box) on an implant order sheet. This sheet is then transferred on a regular basis to the procurement department for replenishment.

Example of a revised replenishment system for items requiring item level traceability. In this case, each time a product package is disposed of in the RFID-enabled receptacle, the information about specific items (unique ID encoded on the RFID tags) is automatically collected by the reader embedded in the receptacle and transferred to the replenishment system.

Fig. 4 Output of RFID-enabled traceability system (i.e. implant sticker sheet vs. computer generated report)

the potential impact of RFID in the healthcare supply chain for consignment and high value items that require item level traceability. Applying the research approach to a hospital operating room environment indicates that implementing the RFID-enabled traceability system in conjunction with the redesign of replenishment processes can substantially facilitate item level traceability, improve financial controls and case costing, and upgrade service levels, while reducing costly inventory shrinkage. Other benefits for the hospital are also derived from the time saved from non-value-added activities that can be transferred to patient care activities. The solution can be considered

(i) as an alternative to RFID-enabled cabinets used in the replenishment of consignment and high value supplies in certain operating rooms, cardiac catheterization laboratories and interventional radiology departments by enabling the tracking of items from reception to consumption. Instead of having real-time count of on-hand inventory (i.e. notifying a transaction each time a product is put away or removed from a cabinet), the proposed system presumes the availability of the supplies until there is a read in a receptacle. Indeed, this system provides real time management of consumption of items vs. real time on-hand inventory, triggering the replenishment process when an item is really used. On the other hand, in the situation where the cost of cabinets or space for cabinets are an issue, the RFID-enabled receptacle can be an alternative to the management of traceable items,

(ii) as a complementary solution facilitating the tracking of medical devices removed from RFID-enabled cabinets by adding the level of consumption traceability and associating it with a specific medical procedure and patient. In short, the end-to-end traceability of medical products in the healthcare supply chain can be significantly enhanced.

When the healthcare supply chain members are included in the replenishment process through the use of EDI, many other benefits can be derived such as (i) rapid, efficient and accurate automatic electronic transmission of business data between healthcare supply chain members, (ii) improved data accuracy in a number of supply chain processes from production to point of care, and (iii) reduced time spent on administrative and clerical duties, allowing more time to be dedicated to the main priority—patient care.

In the context of an open loop supply chain that links internal and external traceability, a question can be raised concerning to the choice of the chosen RFID frequency: an HF solution or a UHF alternative based on the EPC Global standards that are specifically designed for SCM applications. In this specific case, the choice of HF technology was motivated by different reasons: (i) historical: related to the availability of the system in 2006 when UHF RFID performances were still very limited and standards non existent, (ii) performance: as HF technology is less sensitive to metallic and liquid products omnipresent in the OR/cat lab environments (iii) process requirement: as the application requires short range reads limiting the data capture to the products disposed of in the receptacle (iv) security issue: related to potential Electromagnetic Interference (EMI) caused by the RFID system. In July 2009 the Health Industry Business Communications Council (HIBCC) proposed a new standard for RFID, also known as ANSI/HIBC 4.0, which received a final approval by the American National Standards Institute (ANSI). This standard recommended that the HF frequency be adopted for healthcare item level tagging because its smaller read range is less likely to result in EMI with medical devices [41].

Nonetheless, as the performance of passive UHF RFID technologies has drastically evolved in recent years, and now presents great reading performances in near field for item level tagging, one option, and a future research avenue, would be to explore in more detail its use for the RFID-enabled traceability system discussed in the paper. For now, the healthcare sector is moving towards the standardization of supply chain processes [42], but the sector has not yet reached a level of traceability maturity where supply chain members can collaborate proactively to achieve traceability across the entire supply chain. Some global healthcare traceability standards already exist (e.g. Global Standard One/GS1, Health Industry Bar Code Standards/HIBICS), but their adoption is a relatively recent phenomenon compared to the retail sector. Therefore, it might take several years before RFID technologies and the Electronic Product Code (EPC) become the standard for item level traceability in the health care sector. Until then, the current HF solution meets current healthcare and traceability requirements.

This paper concludes with a comment on the need to conduct further research on RFID SCM applications in the healthcare sector as this area holds great potential for health-care performance improvements. There is also a need to conduct more in-depth research into the impact of RFID technology isolated it from the impact of change management and process redesign initiatives that are tied to it. Finally, while the results should be interpreted cautiously as they are based on a single hospital case study, the research design integrating BPR and ABC approaches can provide a good indication for practitioners on how to evaluate the impact of such RFID systems on hospital supply chain performances.

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References

1. GS1 (2009) Traceability: What's in it for you: What GS1 can do to help. http://www.gs1.org/docs/traceability/traceability_brochure.pdf. Accessed 24 October 2011.
2. GS1. (2009) GS1 Standards document business process and system requirements for supply chain traceability: Global traceability standard for healthcare. http://www.gs1.org/docs/gsmp/traceability/Global_Traceability_Standard_Healthcare.pdf Accessed 24 October 2011.
3. Boeck, H., and Fosso Wamba, S., RFID and buyer-seller relationships in the retail supply chain. *Int. J. Retail. Distrib. Manag.* 36(6):433–360, 2008. doi:10.1108/09590550810873929.
4. Voulodimos, A. S., Patrikakis, C. Z., Sideridis, A. B., Ntafis, V. A., and Xylouri, E. M., A complete farm management system based on animal identification using RFID technology. *Comput. Electron. Agric.* 70(2):380–388, 2010. doi:10.1016/j.compag.2009.07.009.
5. Ruiz-Garcia, L., Steinberger, G., and Rothmund, M., A model and prototype implementation for tracking and tracing agricultural batch products along the food chain. *Food Control* 21:112–121, 2010. doi:10.1016/j.foodcont.2008.12.003.
6. Kvarnstrom, B., and Vanhatalo, E., Using RFID to improve traceability in process industry Experiments in a distribution chain for iron ore pellets. *J. Manuf. Technol. Manag.* 21(1):139–154, 2010. doi:10.1108/17410381011011524.
7. Palsson, H., and Johansson, O., Supply chain integration obtained through uniquely labelled goods A survey of Swedish manufacturing industries. *Int. J. Phys. Distrib. Logist. Manag.* 39(1):28–46, 2009. doi:10.1108/09600030910929174.
8. Wasserman, E., RFID in the Forest. *RFID J* 8(1):20–28, 2011.
9. California State Board of Pharmacy (2008) Questions and answers relating to the California electronic prescription drug pedigree law (s). http://www.pharmacy.ca.gov/forms/pedigree_q_and_a.pdf. Accessed 24 October 2011.
10. Ilie-Zudor, E., Kemény, Z., Van Blommestein, F., Monostori, L., and Van der Meulen, A., A survey of applications and requirements of unique identification systems and RFID techniques. *Comput. Ind.* 62:227–252, 2011. doi:10.1016/j.compind.2010.10.004.
11. US Department of Defense,Department of Defense (2008) Guide to uniquely identifying items: Assuring valuation, accountability and control of government property. http://www.acq.osd.mil/dpap/UID/attachments/DoDUIDGuide.pdf Accessed 24 October 2011.
12. Crounse, B., Feied, C., Jordan, N., Kanhouwa, M., Kavanagh, J., The new world of healthcare work: UK focus international lecture, The Royal Academy of Engineering, London, 2006. www.raeng.org.uk/events/pdf/ukfocus_lecture_summary.pdf Accessed 24 October 2011.
13. Porter, M. E., Teisberg, E. O., Redefining health care: creating value-based competition on results. Harvard business school publishing, 2006.
14. Womack, J. P., and Jones, D. T., *Lean thinking: banish the waste and create wealth in your corporation*. Simon & Schuster, London, 1996.
15. Black, J., Miller, D., The Toyota way to healthcare excellence: increase efficiency & improve quality with lean. Health Administration Press, 2008.
16. Womack, J. P., Jones, D. T., and Roos, D., *The machine that changed the world: the story of lean production*. Rawson Associates, Macmillan Publishing Company, New York, 1991.
17. Manos, A., Sattler, M., and Alukal, G., Make healthcare lean. *Qual. Prog.* 39(7):24–30, 2006.
18. de Souza, L. B., Trends and approaches in lean healthcare. *Leadersh Health Serv* 22(2):121–139, 2009. doi:10.1108/17511870910953788.
19. Landry, S., and Beaulieu, M., Achieving lean healthcare by combining the two-bin kanban replenishment system with RFID technology. *Intern J Health Manag Inf* 1(1):85–98, 2010.
20. Bendavid, Y., Boeck, H., and Philippe, R., Redesigning the replenishment process of medical supplies in hospitals with RFID. *Bus. Process. Manag. J.* 16(6):991–1013, 2010. doi:10.1108/14637151011093035.

21. Nachtmann, H., Pohl, E. A., The state of healthcare logistics, cost and quality improvement opportunies. Center for Innovation in Healthcare Logistics, University of Arkansas, 2009.
22. Lambert, D., *Supply chain management, process, partnership, performance*, 3rd edition. Supply chain management institute, Sarasota, Florida, 2008.
23. Sarac, A., Absi, N., and Dauzere-Peres, S., A literature review on the impact of RFID technologies on supply chain management. *Intern J Prod Econ* 128:77–95, 2010. doi:10.1016/j.ijpe.2010.07.039.
24. Kumar, S., Swanson, E., and Tran, T., RFID in the healthcare supply chain: usage and application. *Intern J Healthc Qual Assur* 22(1):67–81, 2009. doi:10.1108/09526860910927961.
25. Chow, G., and Heaver, T., Logistics in the Canadian health care industry. *Can Logist J* 1(1):29–74, 1994.
26. Ontario Buys & Healthcare Supply Network. Supply chain modernization in Ontario health care: Improving patient care, enhancing service levels and reducing costs: A report on the e-supply chain project. Ontario Ministry of Finance, 2007. http://www.hscn.org/PDFs/eSupplyChainReport_FINAL_web_ENG.pdf Accessed 10 January 2011.
27. Friesen, S., Rattling the supply chain: The opportunity for supply chain management in healthcare. University of Waterloo, 2005. http://infranet.uwaterloo.ca/infranet/s200503.htm. Accessed 24 October 2011.
28. Stanley InnerSpace. RFID enabled clinical supply management solution, 2010. http://www.stanleyinnerspace.com/node/158. Accessed 24 October 2011.
29. Harrop, P., Das, R., Holland, G., RFID for Healthcare and Pharmaceuticals 2009–2019. IDTechEx, 2009.
30. Van Oranje, C., Schindler, R., Vilamovska, A. M., Botterman, M., Policy options for radio frequency identification (RFID) application in healthcare; a prospective view: Final report (Deliverable 5), 2010. http://www.rand.org/pubs/technical_reports/2010/RAND_TR767-1.pdf. Accessed 24 October 2011.
31. GS1 Canada. EPC/RFID in Healthcare. GS1 knowledge center, 2010. http://www.gs1ca.org/page.asp?intPageID=1428. Accessed 24 October 2011.
32. Wicks, A. M., Visich, J. K., and Li, S., Radio frequency identification applications in healthcare. *Int. J. Healthc. Technol. Manag.* 7(6):522–40, 2006.
33. Edwards, J., RFID Smart Shelves and Cabinets. RFID Journal, 2009. http://www.rfidjournal.com/article/view/5140. Accessed 24 October 2011.
34. Yin, R. K., *Case study research: Design and methods*, 3rd edition. Sage, Thousand Oaks, 2002.
35. Kaplan, R. S., and Anderson, S. R., *Time-driven activity-based costing: Simpler and more powerful path to higher profits*. Harvard Business School Press, Boston, 2007.
36. Bunduchi, R., Weisshaar, C., and Smart, A. U., Mapping the benefits and costs associated with process innovation: The case of RFID adoption. *Technovation* 31(9):505–521, 2011. doi:10.1016/j.technovation.2011.04.001.
37. Bendavid, Y., Ng, E., Developing an RFID Business Case and Calculating the ROIRFID Preconference: RFID for Warehouse and Inventory Management. *RFID Journal Live 2011*, ninth annual conference and exhibition, Orlando, 2011.
38. Smart, A. U., Bunduchi, R., and Gerst, M., The costs of adoption of RFID technologies in supply networks. *Int J Oper Prod Manag* 30(4):423–447, 2010. doi:10.1108/01443571011029994.
39. Bahri, S., Managing the implementation of an innovative technology in: a hospital a case study. *J. Syst. Inf. Technol.* 11 (3):269–285, 2009. doi:10.1108/13287260910983632.
40. Roberti, M., Labor savings can be illusive. *RFID J* 7(6):6–7, 2010.
41. Health Industry Business Communications Council. ANSI approves HIBCC standard that addresses RFID/medical device safety concerns, 2009. http://www.hibcc.org/RFID.htm. Accessed 24 October 2011.
42. GS1 (2011) GS1 Healthcare Newsletter, No. 22, Quarter 2. http://www.gs1.org/docs/healthcare/GS1_Healthcare_Newsletter_22_Q2_2011.pdf. Accessed 24 October 2011.
43. Bendavid, Y., and Boeck, H., Using RFID to improve hospital supply chain management for high value and consignment items. *Procedia Comput Sci* 5:849–856, 2011. doi:10.1016/j.procs.2011.07.117.